Hazard Screening of Chemical Releases and Environmental Equity Analysis of Populations Proximate to Toxic Release Inventory Facilities in Oregon

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A comprehensive approach using hazard screening, demographic analysis, and a geographic information system (GIS) for mapping is employed to address environmental equity issues in Oregon. A media-specific chronic toxicity index [or chronic index (CI)] was used to compare environmental chemical releases reported in the EPA's Toxic Chemical Release Inventory (TRI) database. In 1992, 254 facilities reportedly released more than 40 million pounds of toxic chemicals directly into the environment on-site or transferred them to sewage treatment plants or other off-site facilities for disposal and recycling. For each reported on-site TRI chemical release, a CI based on oral toxicity factors and total mass was calculated. CIs were aggregated on a media-, facility-, and chemical-specific basis. Glycol ethers, nickel, trichloroethylene, chloroform, and manganese were ranked as the top five chemicals released statewide based on total CI. In contrast, based on total mass, methanol, nickel, ammonia, acetone, and toluene were identified as the top five TRI chemicals released in Oregon. TRI facility rankings were related to the demographics and household income of surrounding neighborhoods using bivariate GIS mapping and statistical analysis. TRI facilities were disproportionately located in racial and ethnic minority neighborhoods. They were also located in areas with lower incomes compared to those in the surrounding county. No relationship was observed between the hazard ranking of the TRI facilities overall and socioeconomic characteristics of the community in which they were located.
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The purpose of this study was twofold: to rank the chronic toxic potential of environmental chemical releases reported in the EPA Toxic Release Inventory (TRI) database for Oregon and to apply these results to demographic and socioeconomic data obtained with a geographic information system (GIS). This study addresses equity issues relating to the proximity of households to individual and multiple TRI facilities releasing toxic chemicals into the environment. Many of these chemicals are associated with a diverse and wide range of potential adverse health outcomes.

In the first phase, a media-specific chronic toxicity index, or chronic index (CI), was used to rank TRI chemical releases. The TRI database was selected because it is widely available and provides comprehensive annual data on hazardous environmental chemical emissions (*1*). During the 1992 TRI reporting year, Oregon ranked thirty-third in the nation based on the total pounds of TRI chemicals released on-site (e.g., air, land, and water) (*2*). The major manufacturers in Oregon reporting on-site chemical releases during this time period included pulp and paper mills, smelters and foundries, producers of film and resin materials, transportation equipment manufacturers, chemical manufacturers, and electronics industries.

The CI is a component of the Chemical Indexing System developed by the EPA's Region III Air, Radiation and Toxics Division (*3,4*). This system utilizes the EPA's TRI database and chronic oral toxicity factors for both carcinogens and noncarcinogens to estimate and compare the relative hazards of TRI chemical releases. This hazard screening tool was designed to improve the current ranking scheme of simply adding masses of different pollutants to obtain a total mass for a specific TRI facility or state (*2*). Ranking based on mass alone can unfairly represent TRI facilities and lead to faulty pollution prevention decisions by emphasizing the volume of chemical releases without regard for properties of the chemicals (i.e., toxicity or environmental fate). Other investigators have used various toxicity weighting approaches to rank and compare environmental chemical releases (*5–7*). Although these studies have merit, their approach to toxicity generally has been coarsely defined. The threshold limit value (TLV) methodology recently developed by Horvath et al. (*8*) is noteworthy; however, TLVs are intended for application in an occupational rather than environmental setting and may not fully protect all segments of the population (*9–11*).

Risk assessment is a multistage process that ultimately requires information on the toxicity of a particular chemical and its effect on human health, knowledge of the demographics and health status of the population at risk of exposure, and the most accurate information on measured or estimated exposures (current and previous exposures if one is interested in health effects with long latencies after exposure) (*12*). The costs associated with conducting comprehensive risk assessment studies preclude that they be implemented whenever there is an environmental health problem. The CI only considers the components of the risk assessment process that describes hazard identification (*13*). Therefore, the results of the CI are not intended to describe population or individual risk. Instead, this approach is iterative and serves as an initial screening tool to identify potential hazards and evaluate the need for further action such as exposure assessment or full risk assessment. The ranking of TRI emissions using the CI combined with knowledge about the demographics of the communities at risk of exposure such as population density, race, ethnicity, socioeconomic status, and age is an attempt to help set priorities for future risk or public health assessments, epidemiological studies, and basic research on cellular mechanisms associated with environmental health problems.

During the past 13 years, federal, state, and local government agencies, academic researchers, and environmental groups have reported that exposures to environmental pollutants are inequitably distributed among the U.S. population. Many studies have demonstrated that environmental hazards including hazardous waste sites, hazardous waste incinerators, industrial emissions, and agricultural pesticide use are disproportionately located

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among racial and ethnic minority populations, including Black, Asian, Native American, and Latino communities (*14–18*). In several instances, inequities were apparent regardless of the socioeconomic status of the residents living in the affected community (*14*). Perlin et al. (*15*) found that household incomes actually were higher in some communities with higher industrial emissions. Previous studies have analyzed the number of hazardous waste sites or the amount of chemical emissions within identified communities but have not compared with the overall population the toxicity of the pollutants or the extent of exposure within geographically defined areas. Earlier studies addressing issues of environmental equity generally used larger geographic units of analysis such as block groups, census tracts, or municipalities (*7,15–17*). As recently noted by Glickman et al. (*19*), local variations can be masked and anomalies such as minority or low income clusters obscured using these larger geographic boundaries. A unique aspect of the present study is that block-level data (the smallest available geographic census unit), including racial, ethnic, and socioeconomic characteristics such as housing value and estimated household income, were analyzed within 0.7–2.0 miles of each TRI facility in relation to the relative toxicity of TRI chemical releases. This appears to be the first study to combine hazard screening, demographic analysis, and GIS technology to address environmental equity issues surrounding TRI facilities.

Methods

Databases

TRI. The 1992 TRI database for Oregon was extracted from a component file of the National Library of Medicine's TOXNET system and from the EPA. The TRI database was originally established under Section 313 of Title III of the Superfund Amendments and Re-authorization Act and is known as the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 (*1*). EPCRA requires manufacturing facilities that meet certain thresholds to report their estimated releases and transfers of toxic chemicals to the EPA. Releases include unplanned spills and routine emissions of chemicals released directly to the air and land, injected into land, discharged to surface water, or transferred to publicly owned treatment works commonly known as sewage treatment plants, or other off-site locations for recycling and waste disposal.

IRIS. The EPA's Integrated Risk Information System (IRIS) database provides oral toxicity factors for most of the EPCRA chemicals and is available through the National Library of Medicine's TOXNET system or from the EPA. IRIS provides quantitative estimates of toxicity for both carcinogens and noncarcinogens derived using a consistent, established procedure (*20–22*). Toxicological data for individual chemicals in IRIS undergo extensive peer review, and the resulting values are widely accepted. Moreover, this database is updated periodically, primarily to account for new additions. As new information becomes available in the literature, existing chemical files are reassessed and any changes are included in the monthly updates.

HEAST. The EPA's National Center for Exposure Assessment in Cincinnati, Ohio, prepares a list of toxicological data in the form of Health Effects Assessment Summary Tables (HEAST). These data undergo extensive peer review and are updated annually. The information in this database is considered provisional because the values do not have the concurrence of all EPA program offices. Each value is supported by an EPA reference; however, the information has not had enough review to be recognized as agency consensus (*23*).

U.S. Bureau of Census. Data from the 1990 U.S. Bureau of Census were used to aggregate and analyze demographics in Oregon according to total population, race (white; black; American Indian, Eskimo, or Aleut; Asian or Pacific Islander, and other races), ethnicity (Hispanic), and household income. Census information for block level data was extracted from 100% count data in CD-ROM Summary Tape Files STF1A and B, and block group level data used to tabulate median income was obtained from sampling data in STF3 tables (*24*).

Chronic Toxicity Algorithm

Individual CIs were calculated for each on-site chemical release reported for Oregon during 1992. The CI, as previously described (*3–4*), is based on a combination of TRI emission data and oral toxicity factors for each TRI chemical. A major strength of this toxicity weighting approach is that it allows direct comparison of carcinogenic and noncarcinogenic TRI chemicals by adjusting both dose scales. It is important to note that this adjustment is not intended to imply biological significance of the individual toxic effects but maintains consistency with EPA policies regarding the regulation of risk and hazard levels for carcinogens and noncarcinogens (*4*).

Because risk at low exposure levels cannot be directly measured, mathematical models are used to extrapolate animal or epidemiological data obtained at high doses to project the risk at very low doses. In the absence of adequate information supporting other model types, the EPA employs a conservative approach by using the linearized multistage model for low dose extrapolation (*25*). The CI algorithm adjusts the scale for carcinogens by calculating the dose at a risk level of 1×10^{-4} according to the one-hit dose–response model shown in Equation 1. The one-hit model is based on the concept that a tumor can be induced after a single susceptible target or receptor has been exposed to a single effective dose unit of a substance. Therefore, in keeping with the screening objective of the CI, this dose–response model provides a conservative estimate of the dose associated with the reference risk. Using a reference risk level of 1×10^{-4} is consistent with EPA policy for carcinogens regulated under the National Contingency Plan (NCP) and the Clean Air Act Amendments of 1990 (*26*). Carcinogenic TRI chemical dose scales were adjusted using the following equation:

$$\text{Risk} = 1\text{-}e^{-q^* d_c} \qquad (1)$$

where the risk level = 1×10^{-4} as reference risk value, q^*= cancer potency factor [CPF; (milligrams per kilogram per day)$^{-1}$], and d_c= carcinogenic dose (milligrams per day).

To account for the adequacy of the database supporting the carcinogenicity assessment, the EPA has derived weight-of-evidence classifications (WOE) (*27*). These WOE classifications of A, B1, B2, C-B2, and C are represented by mathematically equivalent internals as described by Forman (*4*), where A = 1.0; B1 = 0.84; B2 = 0.67; C-B2 = 0.51; and C = 0.34. Finally, to express all hazard doses in units equivalent to the theoretical exposure dose units (milligrams per day), an average adult body weight of 70 kg is used to adjust the kilogram body weight factor.

Solving for d_c, we have

$$d_c = \frac{\ln (1\text{-}(1 \times 10^{-4}) \times WOE^* \times BW^{**}}{\text{-}CPF}, \qquad (2)$$

where WOE^* = carcinogenic weight of evidence and BW^{**} = body weight.

For noncarcinogens, EPA policy under the Superfund Program (the NCP) recommends concentrations "to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety" (*28*). Therefore, the CI algorithm calculates the dose scale for noncarcinogens (*nc*) using concentrations equivalent to a hazard index of 1, which is equal to the oral reference dose (RfD). The following equation is used for noncarcinogenic TRI chemical dose adjustments:

$$\text{Dose}_{nc}\,(\text{mg/day}) = \text{RfD}\,(\text{mg/kg/day}) \times BW \quad (3)$$

where RfD = oral reference dose = hazard index = 1.0.

If the TRI chemical possessed both noncarcinogenic and carcinogenic toxicity factors, a total hazard dose was calculated using the following equation:

$$\text{Hazard Dose}_T\,(\text{mg/day}) = \frac{1}{\frac{(1)}{D_{nc}} + \frac{(1)}{D_c}}. \quad (4)$$

A theoretical exposure dose (milligrams per day) is then calculated using the reported total mass (pounds per year) released on-site and various conversion factors, as shown in the following equation:

$$\text{Theoretical Exposure Dose (mg/day)} = \frac{\text{mass (lbs/year)} \times 0.453\ (\text{kg/lb}) \times 1{,}000{,}000\ \text{mg/kg}}{365\ \text{days/year}}, \quad (5)$$

where 1 lb = 0.453 kg chemical, 1 kg chemical = 1×10^6 mg chemical, and 1 year = 365 days.

This theoretical exposure dose serves as the numerator in the CI equation and is divided by the previously calculated dose_{nc}, dose_c (milligrams per day), or total hazard dose. The resulting CI expresses relative hazard and is unitless. CIs can be aggregated on a media-, facility-, or chemical-specific basis.

$$\text{CI} = \frac{\text{Theoretical Exposure Dose (mg/day)}}{\text{Hazard Dose (mg/day)}}. \quad (6)$$

Geographic Information System Mapping and Demographic Analysis

ARC/INFO (Environmental System Research Institute, Redlands, CA) was initially used to build spatial databases and mapping layers. Final database development and mapping was done with MapInfo 4.0 (MapInfo Corp., Troy, NY) on a PowerMacintosh 8100/110 computer (Apple Computer, Inc., Cupertino, CA). The geographic boundary files were constructed from TIGER files (Bureau of the Census, Washington, DC). Geographic files included census-block and census-block group boundaries and county boundaries, as well as files of rivers, individual streets, and road and rail networks. The state of Oregon consists of 2,575 block groups and 61,075 census blocks containing household census data.

Geographical coordinates (e.g., latitude and longitude) contained in the TRI database were used to locate TRI facilities. These coordinates are provided by the reporting facility on the TRI reporting form (Form R). The coordinates presented in our data set were cross-checked using address- and zip code-matching programs. Inaccuracies were identified in 30% of the coordinates reported in the original TRI data set. Personnel from those TRI facilities with latitude or longitude coordinate discrepancies were contacted and interviewed, and the geographic coordinates in our data set were corrected. The EPA was notified of these inaccuracies.

Analysis of demographic data (race, ethnicity, estimated household income) was conducted at the census-block level of aggregation. Circles with radii of 0.71, 1.00, 1.41, 1.73, and 2.00 miles were drawn around each TRI facility. The area within 1.0 mile of a TRI site was equivalent to the area between circles 2 and 3, circles 3 and 4, and circles 4 and 5. These radii were chosen to standardize the area of each ring to equal pi square miles. The area within 0.71 miles (circle 1) was equal to the area between circles 1 and 2. The 1990 census-block data were aggregated from all census blocks in which the centroid of the block fell within the designated circle drawn around the TRI site using a point-within-a-polygon analysis. Block data within the areas proximate to the sites were assigned to pollutants released from one or multiple TRI facilities. In alternate geographic analysis, 1.0 mile circular radii were drawn around the centroid of individual census blocks rather than around each TRI facility, and the CIs were aggregated from all TRI facilities falling within 1.0 mile of each census block centroid. All sites were located within a mile of at least one block centroid. This approach was desirable in urban and industrial areas where there may be multiple sources of environmental pollutants close to residential areas. Bivariate mapping was used to identify numbers and distribution of minority populations and household incomes and to demonstrate the relationship between population demographics and CI rank for each TRI facility.

Statistical Analysis

Statistical analysis was conducted using Microsoft Excel (Microsoft, Redmond, WA) and S-Plus (StatSci) computer software. Nonparametric statistics (chi-square) were used to analyze the racial and ethnic characteristics within the buffer region relative to those of the general population in the county in which the facility was located, as well as the entire state. Statistical analysis relying on a paired *t*-test and the nonparametric Wilcoxon test for paired data were used to analyze estimated household median income near TRI sites relative to estimated median income for county households. A nonparametric Wilcoxon rank-sum test was used to analyze the median chronic index of the TRI sites with positive or negative income excesses (county income minus site income) in areas within 1.0 mile of each facility. Scatterplots and analysis of variance (ANOVA) were used to analyze the response of the CI or mass of TRI chemicals released on-site with the percentage of racial and ethnic minorities living within 1.0 mile of a TRI site.

Estimate of Household Income

Although the 1990 Census provides data on race and Hispanic status at the block level (tabulated from 100% survey count), it does not give data on a block level for household income (*24*). It does, however, provide block-level surrogates for income such as housing values, rents, and population crowding. For this project, estimates of median household income on the block level were computed by the Center for Population Research and Census at Portland State University, using other available block-level demographic data and the block-group income data contained on CD-ROM STF3A tabulated from the census long-form sample data (*29*). An initial multiple regression model was built using block-group data to estimate block-group income. Surrogates of income, including housing values, rent, owner/renter status, age of residents, and crowding, were used to predict household income for the 2,575 block groups containing households in Oregon. The regression equation used to calculate square root of household income was

$$10.510 + 0.190x_1 + 3.499x_2 + 0.947x_3 - 0.403x_4 + 1.955x_5 - 208.280x_6, \quad (7)$$

where x_1 = square root of housing value (0.007), x_2 = square root of rent (0.156), x_3 = percent occupancy (0.041), x_4 = percent age >65 (0.050), x_5 = percent age <18 (0.063), and x_6 = number of persons per room (7.36). The values in parentheses are the standard errors for each coefficient. The Pearson's R^2 for this prediction was 0.70. The results of this regression model were then applied to the 61,075 census blocks and the median income for blocks estimated. Blocks that contained data for all the household variables included 84.5% of the housing and 85.5% of the population. Separate regression equations were used for the blocks for which housing value and/or rent information was missing when blocks were wholly owner or renter occupied. The Pearson's R^2 values for these regressions ranged from 0.70 to 0.90. The aggregated estimated income for blocks within each

census block group was summarized and compared to the census value for block group, and the block incomes were scaled up or down to force the estimated aggregated block-level income to equal the reported block-group income. The results of this model generally differentiated lower versus higher income blocks better in densely populated urban areas and less well in rural areas where housing value and rent information was sparse. Estimates of block-level median household income were aggregated, and the average estimated median income for the area in question, i.e. within 1.0 mile of a TRI facility or within the entire county, was determined by the following equation:

$$\text{Average aggregated median household income} = \frac{\Sigma(\text{No. of households} \times \text{estimated median household income})}{\Sigma\,(\text{No. of households})}. \quad (8)$$

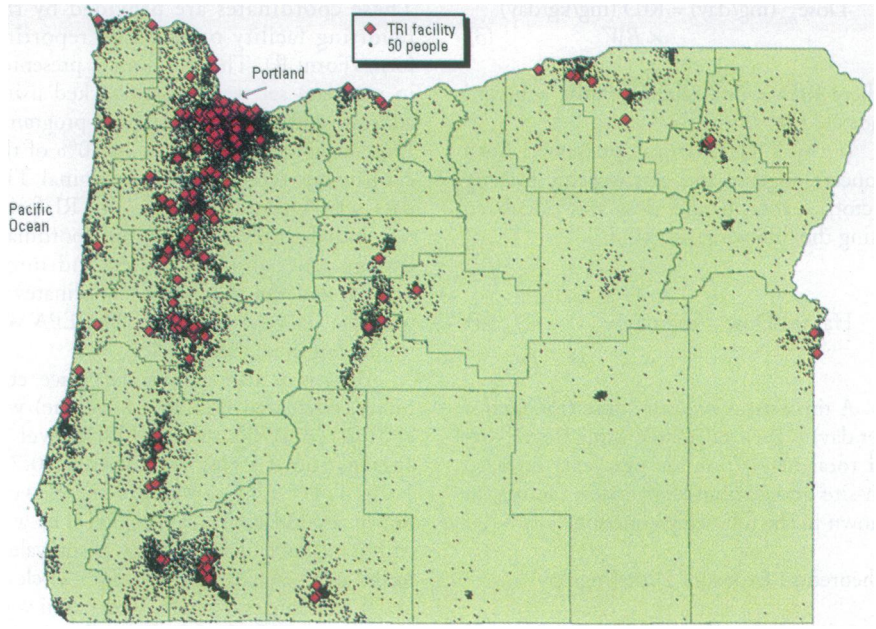

Figure 1. Distribution of Toxic Chemical Release Inventory (TRI) sites in Oregon and total population density. The total population of Oregon was 2.84 million according to the 1990 U.S. Census (*24*).

Results

Distribution of TRI facilities, releases, and population density. During 1992, more than 40 million lbs of toxic chemicals were released on-site or transferred off-site for recycling or disposal by 254 different manufacturing facilities in Oregon. Almost half this quantity was released on-site directly into the environment either through air emissions, land releases, or discharges into surface water. An additional 17 million lbs (41% of total releases) were transferred to off-site locations for recycling and disposal, whereas the remaining 10% was released to publicly owned treatment works. Underground injection is an illegal waste disposal practice in Oregon, and there were no reported releases using this method of disposal. The present study examined only on-site chemical releases.

More than 80% of the TRI facilities are located in a highly populous corridor in western Oregon within the Willamette River Basin (Fig. 1). This area comprises only 12% of the state's area but contains most of the urban centers and almost 70% of the state's population.

Chronic toxicity ranking of TRI chemical releases. During 1992, 229 facilities listed in Oregon's TRI reported on-site releases of 81 different TRI chemicals or chemical classes into the air, water, or land. Table 1 lists the top 20 TRI chemicals released on-site (air, water, or land) based on total pounds. Methanol, nickel, ammonia, acetone, and toluene were identified as the top five TRI chemicals. Sixty-seven percent (54/81) of the TRI chemicals released on-site—constituting 85% of the total mass or 16.6 million lbs—had chronic oral toxicity factors and could be ranked using the CI approach (data not shown). Chemical releases could be ranked for a total of 196 TRI facilities using CIs based on the availability of oral toxicity factors. Most of the remaining TRI chemicals without CI rankings are acute toxicants (i.e., irritants, corrosives) such as ammonia, hydrochloric acid, chlorine, and sulfuric acid. One important exception is that 3,847 lbs of lead compounds were released into the environment (250 lbs into water and 3,597 lbs into air) by 12 TRI facilities in 1992. Although lead poses chronic health risks, there are no chronic oral toxicity factors available for this chemical in either IRIS or HEAST. Instead lead hazards are calculated using a biokinetic model that predicts blood lead levels in children exposed to lead from different environmental sources, i.e., diet, air, water, soil, and dust.

For those 54 TRI chemicals with oral toxicity factors, there was a 625,000-fold range in the total relative dose, which considers both noncancer and cancer effects. As shown in Table 2, arsenical compounds (Class A carcinogens) were identified as the most toxic TRI chemical released on-site, whereas the chlorofluorocarbon Freon 113 was identified as the least toxic. It is important to note, however, that the CI does not take into account ecological or environmental health risks such as those associated with chlorofluorocarbon-induced stratospheric ozone depletion. Carcinogenic TRI chemicals released on-site constituted 8.4% of the total mass. Two Class A or known human carcinogens were released, including 531 lbs of arsenical compounds into water and 1,384 lbs of benzene into the air. Of all classes of carcinogens, the B2 or probable human carcinogen chloroform was released in the largest quantity (412,297 lbs) by both point and nonpoint air emissions.

Table 1. Top 20 Toxic Chemical Release Inventory (TRI) chemicals released on-site in Oregon in 1992 based on total mass and total chronic index

Total mass	Total chronic index
Methanol	Glycol ethers
Nickel	Nickel and nickel compounds
Ammonia[a]	Trichloroethylene
Acetone	Chloroform
Toluene	Manganese compounds
Methyl ethyl ketone	Dichloromethane
Formaldehyde	2-Methoxyethanol
Xylene (mixed isomers)	Acetone
Hydrochloric acid[a]	Hexachloroethane
Methyl isobutyl ketone	Chromium and chromium compounds
Trichloroethylene	Arsenic compounds
1,1,1-Trichloroethane	Methanol
Chloroform	Methyl isobutyl ketone
Styrene	Toluene
Dichloromethane	1,1,1-Trichloroethane
Freon 113	Formaldehyde
Manganese compounds	Naphthalene
Glycol ethers	Epichlorohydrin
Chlorine[a]	Methyl ethyl ketone
Sulfuric acid[a]	Styrene

[a]TRI chemicals that did not have toxicity factors (oral reference doses and cancer potency factors) available in IRIS or HEAST databases.

Results of ranking individual TRI chemicals based on total CI, which considers both toxicity and mass, are presented in Table 1. Glycol ethers had the greatest total CI of 3.5×10^9 because of the relatively large quantity released into air

(141,286 lbs) and water (59,400 lbs) (data not shown) and relatively high toxicity (relative dose = 0.07 mg/day). In contrast, glycol ethers were ranked eighteenth based solely on total mass (Table 1). Nickel and nickel compounds ranked second for all on-site TRI releases using either method. One facility, a nickel smelter, contributed 97% of the total CI for nickel-containing slag. The industrial solvents trichloroethylene and chloroform ranked third and fourth, respectively, based on total CI while placing eleventh and thirteenth based solely on total mass.

CIs for individual TRI chemicals were aggregated on a media-specific basis, as shown in Table 3. Eighty-five percent (2,324,645 lbs) of all TRI chemicals released onto land could be ranked using the CI (data not shown). Following CI ranking, nickel, manganese, chromium, arsenic, and zinc compounds were identified as the top five TRI chemicals released to land (Table 3). Nickel constituted 89% of the total mass released and 68% of the total CI calculated for the land category. With respect to air releases, 83% of the total mass released by point sources and 90% of the nonpoint air emissions could be ranked using the CI (data not shown). TRI chemicals released into the air with the greatest CI were glycol ethers, trichloroethylene, chloroform, dichloromethane, and hexachloroethane (Table 1). Only 38% of all surface-water releases could be ranked using the CI because the TRI chemical released into water in the greatest amounts was the acute irritant ammonia (303,355 lbs or >60% of total mass), which has no chronic oral toxicity factor. Glycol ethers, arsenic, chloroform, pentachlorophenol, and methyl isobutyl ketone had the largest total CIs for TRI chemicals released into water (Table 3).

Table 4 lists the top 10 TRI facilities in Oregon based on total CI for all on-site releases. The nickel-smelting plant had the greatest CI (1.79×10^9) following the reported release of more than 2 million lbs of slag-containing nickel onto the land. Similarly, this facility also ranked first based on total mass of a TRI chemical released on-site in 1992 (data not shown). Large air emissions of glycol ethers and chloroform from a pulp and paper mill resulted in the second place ranking of Facility 2. In contrast, this paper mill ranked sixth based on total mass. Other facilities listed in Table 4 include wood and fabricated metal product manufacturers, steel foundries, and electronics industries.

Demographic analysis of populations residing near TRI facilities. As reported in the 1990 U.S. Census (*24*), the racial demographics of Oregon are as follows: 92.76% white; 1.62% black; 1.35% American Indian, Aleut, or Eskimo; 2.44% Asian or Pacific Islander; and 1.81% other races. The Hispanic ethnic group makes up 3.96% of

Table 2. Top 20 TRI chemicals released on-site in Oregon in 1992 based on total relative dose

Chemical name	WOE[a]	RfD[b] (mg/kg/day)	CPF[b] $(mg/kg/day)^{-1}$	Total relative dose (mg/day)
Arsenic compounds	A	0.0003	1.75	0.003
Propylene oxide	B2	0	0.24	0.019
Antimony and antimony compounds	–	0.0004	–	0.028
Pentachlorophenol	B2	0.03	0.12	0.038
Hexachloroethane	C	0.001	0.014	0.050
Tetrachloroethylene	C/B2	0.01	0.052	0.066
2-Methoxyethanol	–	0.001	–	0.070
Glycol ethers	–	0.001	–	0.070
Ethyl acrylate	B2	–	0.048	0.098
Epichlorohydrin	B2	0.002	0.0099	0.108
Benzene	A	–	0.029	0.241
Naphthalene	–	0.004	–	0.280
Trichloroethylene	C/B2	–	0.011	0.344
Chlorophenols	–	0.005	–	0.350
Chromium and chromium compounds	–	0.005	–	0.350
Manganese and manganese compounds	–	0.005	–	0.350
Chloroform	B2	0.01	0.0061	0.367
Dichloromethane	B2	0.06	0.0075	0.544
2,4-Dichlorophenoxyacetic acid	–	0.01	–	0.700
Nickel and nickel compounds	–	0.02	–	1.400

Abbreviations: WOE, weight of evidence; RfD, oral reference dose; CPF, cancer potency factors; A, known human carcinogen with sufficient evidence from human epidemiological studies; B2, probable human carcinogen with sufficient animal data but no human epidemiological evidence; C, possible human carcinogen with limited evidence in animals and absence of evidence in humans.

[a]U.S. EPA's WOE classification for carcinogens as of May 1994.

[b]Oral RfD and CPF obtained from either IRIS (*20–22*) or HEAST (*23*) databases.

Table 3. Top five Toxic Chemical Release Inventory (TRI) chemicals released on-site in Oregon in 1992 based on total chronic indices (CI) by media

Chemical	Media	Amount released (lbs)	Total CI[a]
Nickel	Land	2,077,422	1,841,630,277
Manganese and manganese compounds	Land	232,880	825,789,746
Chromium and chromium compounds	Land	82,181	205,112,725
Arsenic compounds	Land	5	1,846,869
Zinc	Land	11,216	662,863
Glycol ethers	Air[b]	141,286	2,504,992,484
Trichloroethylene	Air[b]	478,675	1,628,910,417
Chloroform	Air[b]	405,919	1,510,306,165
Dichloromethane	Air[b]	285,894	651,766,588
Hexachloroethane	Air[b]	12,480	312,401,700
Glycol ethers	Water	59,400	1,053,158,513
Arsenic compounds	Water	506	186,903,131
Chloroform	Water	6,236	21,049,670
Pentachlorophenol	Water	527	17,293,958
Methyl isobutyl ketone	Water	8,000	2,836,791

[a]Individual CIs for each TRI chemical reported from all facilities are summed by the media into which they were released.

[b]Point (stack) and nonpoint (fugitive) emissions.

Table 4. Ranking of 1992 Toxic Chemical Release Inventory (TRI) facilities in Oregon based on total chronic index (CI)

Facility number	Trigger chemicals[a]	Total CI[b]
1	Nickel	1,792,668,159
2	Glycol ethers, chloroform	1,598,286,051
3	Glycol ethers, ethylbenzene	909,200,254
4	Manganese, chromium	886,239,094
5	Trichloroethylene	697,195,300
6	Chloroform, methyl ethyl ketone, methanol	494,788,650
7	Glycol ethers	407,788,650
8	Trichloroethylene, chromium	392,701,333
9	Chloroform	386,701,333
10	2- Methoxyethanol	374,101,761

[a]TRI chemical(s) that contributed most to the total on-site chronic index for each facility.

[b]Individual CIs for all reported chemical releases are summed by facility.

the state's population. Although Oregon's estimated population increased 4.4% from 1990 to 1992 when the TRI data were collected for this study, complete data from the 1990 U.S. Census were used for this research. Available demographics using U.S. Census estimates of minority population data in 1992 were 1.71% black; 1.42% American Indian, Aleut, or Eskimo; and 2.69% Asian or Pacific Islander. The Hispanic group rose to 4.25% of the state's population. Aggregating 1990 census-block level data around each TRI facility indicated that almost 25% (711,132 people) of Oregon's total population lived within 1.0 mile and 50% of all Oregonians lived within 2.0 miles of a TRI facility.

Almost 90% of the population living within 1.0 mile of a TRI site are white, but racial and ethnic minorities are disproportionately located near these facilities. A comparison of the percentages of each racial and ethnic group living close to a TRI facility compared to percentage for each group in the entire state demonstrates that blacks are more than twice as likely as whites to live within 1.0 mile of a TRI facility (Table 5). This is not surprising, as more than 75% of Oregon's black population lives in Multnomah County, which also contains 25% of all TRI facilities. Almost 60% of Oregon's black population lives within 1.0 miles of a TRI site compared to only 25% of the general population; more than 86% of the black population lives within a 2.0 mile radius of a TRI facility. The Asian and Hispanic populations also have a greater likelihood of living near a TRI site compared to the white population, although the differences are smaller.

The proportion of each racial and ethnic minority group was compared at distinct distances from a TRI site. Populations living within 1.0 mile of a TRI facility (within circle 2) were compared to the same racial or ethnic group living between 1.7 and 2.0 miles from a TRI site, (same total areas). As shown in Table 5, as the total population density decreased at greater distances from a TRI site, the percentage of each minority group decreased from 1.0 mile to 2.0 miles as follows: 3.81% to 0.65% for blacks, 1.24% to 0.98% for Native Americans, 3.29 to 3.02% for Asians, and 5.20% to 3.42% for Hispanics. These comparisons show percentage differences that are statistically significant, but the difference for Native American, Asian, or Pacific Islander and other races is less than 1 percentage point.

The demographics of block residents within 1.0 mile of each of the 254 facilities were compared to those of the county in which each facility was located (Table 6). More than 20% of the TRI facilities (51 sites) showed a statistically significant ($p<0.001$) greater percentage of blacks living within 1.0 mile of a TRI facility compared to the percentage of blacks living within the county in which the facilities were located. In addition, 23, 26, and 30% of the sites showed a greater percentage of Native American, Asian or Pacific Islander, and Hispanic populations, respectively, compared to percentages for the county's racial and ethnic characteristics. In many cases, areas showed significant changes in more than one racial minority population and, consequently, the total number of sites that showed significant increases in any minority population was not additive. Rather, there was a total of 120 TRI sites, or 47%, that showed significantly greater percentages of at least one racial minority group, i.e., black, Native American, Asian, and other races compared to the county's demographics. Because the Hispanic population is an ethnic rather than a racial category and includes people of all races, there is some duplication if these groups are added to obtain a total count.

Although there is a disproportionate location of TRI facilities in minority neighborhoods, scatterplots showed no correlation of race or ethnicity associated with the CI of a site or the amount of TRI chemicals reported released. ANOVA results in Tables 7 and 8 demonstrate that the median of CI or total pounds of chemicals released on-site do not differ significantly among the quantile groupings of percentages of racial or ethnic minority populations.

Hazard ranking of the 1992 TRI sites with CI ranging from 0 to 1.79×10^9 resulted in the top 10 sites having CIs that include

Table 5. Cumulative population close to Toxic Chemical Release Inventory (TRI) sites

Circle	Distance[a] (miles)	Population[b]	White	Black	Native American[c]	Asian[d]	Other[e]	Hispanic[f]
0	0	0	0	0	0	0	0	0
1	0.70	412,868	365,654	15,459	5,456	13,209	13,090	24,824
2	1.00	711,132[f] (25%)	632,572 (24%)	27,077 (59%)	8,879 (22%)	23,459 (34%)	19,145 (35%)	37,168 (33%)
3	1.41	1,062,938	954,451	36,695	12,587	34,247	24,948	50,418
4	1.73	1,288,468	1,165,939	38,800	14,704	41,271	27,754	57,414
5	2.00	1,462,581	1,329,379	39,939	16,420	46,526	30,317	63,367
State[g]		2,842,322	2,636,787	46,178	38,496	69,269	51,592	112,707

[a]The radii of circles 1–5 drawn around each TRI facility. The area within circle 1 equals the area between circles 1 and 2. The total area within 1.0 mile (circle 2) is equivalent to the areas between circles 2 and 3, circles 3 and 4, and circles 4 and 5.
[b]Total population living within defined areas of the TRI site (including white; black; Native American; Asian or Pacific Islanders; Hispanics; and other races.
[c]Native American includes American Indian, Eskimo, and Aleut.
[d]Asian includes Asian and Pacific Islanders.
[e]Other includes remaining nonwhite races.
[f]Hispanics are designated as an ethnic population, not a race, and are counted separately by the census. Therefore, a white Hispanic person can be identified and counted as both white and Hispanic.
[g]Percentage of people living within 1.0 mile of a TRI facility divided by the state's total population within each ethnic or racial group.

Table 6. Number of sites with statistically ($p<0.001$) greater percentages of each minority population living within 1.0 mile of a TRI facility when compared to the percentages of minority populations in the county in which sites are located

Number of sites	Percentage of sites	Population compared
51	20	Black
59	23	Native American[a]
52	20	Asian or Pacific Islander
76	30	Hispanic[b]
120	47	Either black, Native American, Asian or Pacific Islander, or other nonwhite races
126	50	Any minority population[c]

TRI, Toxic Chemical Release Inventory.
[a]Native American includes American Indian, Eskimo, or Aleut.
[b]Persons of Hispanic origin may be white or black.
[c]Racial and ethnic minority populations are defined as blacks; Asian or Pacific Islanders; American Indian, Eskimo, or Aleuts not of Hispanic origins; and Hispanics.

Table 7. Relationship of chronic index (CI) or mass of Toxic Chemical Release Inventory (TRI) chemicals released on-site to percent minority population[a]

Quantile	Percent minority[a]	Median [log (CI)][b]	Median [log (lbs released)][c]
I	0–3.2	14.47	9.35
II	3.2–5.5	14.63	9.71
III	5.5–11.2	14.59	8.81
IV	11.2–54.9	14.36	8.81

[a]Percent of total racial minority population including black; American Indian, Eskimo, and Aleut; Asian or Pacific Islander; and other nonwhite races living within 1.0 mile of a TRI facility in Oregon in 1992.
[b]Statistical variance $F_{3,192} = 0.014$; $p = 0.997$.
[c]Statistical variance $F_{3,249} = 0.065$; $p = 0.582$.

Table 8. Relationship of chronic index (CI) or mass of Toxic Chemical Release Inventory (TRI) chemicals released on-site to percent Hispanic population[a]

Quantile	Percent Hispanic[a]	Median [log (CI)][b]	Median [log (lbs released)][c]
I	0–2.2	14.44	9.17
II	2.2–2.9	14.43	9.47
III	2.9–4.8	15.26	9.09
IV	4.78–51.7	14.51	9.59

[a]Percent total Hispanic population living within 1.0 mile of a TRI facility in Oregon in 1992.
[b]Statistical variance $F_{3,192} = 0.014$; $p = 0.997$.
[c]Statistical variance $F_{3,250} = 0.077$; $p = 0.972$.

Table 9. Demographics within 1.0 mile of top 10 Toxic Chemical Release Inventory (TRI) facilities [rank based on total (CI)] compared with those of the county populations in which facility is located

Site number[a]	CI × 1000[b]	Total population near site[c]	White		Black		Native American[d]		Asian or Pacific Islander[e]		Other		Hispanic[e]	
			Site[f]	County[g]	Site[f]	County[g]	Site[f]	County[g]	Site[f]	County[g]	Site[f]	County[g]	Site[f]	County[g]
1	1,792,688	8	100	96.9	0.0	0.2	0.0	1.6	0.0	0.7	0.0	0.7	0.0	2.4
6	1,558,296	27	100	96.4	0.0	0.3	0.0	1.1	0.0	1.3	0.0	0.8	0.0	1.9
37	909,200	6,669	85.2	87.0	6.5	6.0	2.7[h]	1.2[h]	7.0	4.7	2.4[h]	1.2[h]	4.7	3.1
19	886,239	9,920	76.5	87.0	11.8[h]	6.0[h]	2.6[h]	1.2[h]	7.0	4.7	2.1	1.2[h]	4.7	3.1
26	697,195	8,925	85.5	92.0	1.7	0.9	0.9	0.8	10.5[h]	5.5[h]	1.4	0.9	3.2	2.5
5	494,634	2,472	95.8	97.3	0.2	0.1	1.8	1.4	1.5	0.8	0.7	0.5	2.6[h]	1.0[h]
63	407,788	8,925	85.5	92.0	1.7	0.9	0.9	0.8	10.5[h]	5.5[h]	1.4	0.9	3.2	2.5
27	392,672	16,567	94.7	87.0	0.7	6.0	0.7	1.2	3.1	4.7	0.7	1.2	2.0	3.1
10	386,701	6	100	96.9	0.0	0.2	0.0	1.2	0.0	0.9	0.0	0.9	0.0	2.4
67	374,101	2,925	96.2	93.35	0.2	0.3	1.3	1.5	0.7	1.4	1.5	3.5	2.8	5.7

[a]Site numbering is based on pounds of chemicals released on-site.
[b]Total CIs are computed for each TRI facility and include air, water, and land emissions for all chemicals reported.
[c]Total population living within 1.0 mile of the TRI site. Data are from U.S. Bureau of Census (*24*).
[d]Native American includes American Indian, Eskimo, and Aleut.
[e]Hispanics are an ethnic population, not a race, and are counted separately by the census; therefore, a white Hispanic person can be identified and counted as both white and Hispanic.
[f]Percent of race or ethnic population living within 1.0 mile of the TRI site; the percentage is based on count of race or ethnic population divided by total population living within 1.0 mile of site.
[g]Percent of race or ethnic population living within the county in which the TRI facility is located; the percentage is based on count of race or ethnic population in the entire county divided by the total population in the same county.
[h]Sites whose racial and ethnic populations within 1.0 mile of the facility are greater than twice that found in the county in which the facility is located.

nearly 80% of the total CI range (3.7×10^8–1.79×10^9). The top 10 TRI sites (only 4% of all sites) ranked on the basis of total CI for all chemical releases are shown in Table 9. Sites 1, 5, and 6 are ranked among the top 10 by both total pounds released and CI. Seven of these facilities are located in populated urban areas and include three sites in the city of Portland. The percentages of racial and ethnic populations within 1.0 mile of these 10 sites, when compared to those of the neighborhoods within 1.0 mile of all 254 TRI sites (Table 5), are 1.5 times greater among the Asian population and 0.5 times greater among the Hispanic population. No apparent differences were observed among black or Native American populations when the 10 top sites ranked by CI and all TRI sites are compared.

Analysis of populations residing near multiple sites. GIS technology enables analysis of census-block data in overlapping designated regions around each TRI facility. Many of the facilities listed in Table 9 are close to several other TRI facilities; therefore, neighboring populations are at risk from exposure to chemical emissions from multiple facilities. For example, Figure 2 demonstrates the variability in the percentage of blacks within each census block and the overlapping of GIS-defined 1.0 mile radii boundaries around the individual TRI facilities ranked by CI. The total amount of chemicals released from Site 37 (Table 9) is 107,750 lbs, but a portion of the population living within 1.0 mile of this facility is also located within 1.0 mile of other TRI sites. Therefore, the total reported TRI chemical releases within 1.0 mile of this neighborhood is actually 359,928 lbs.

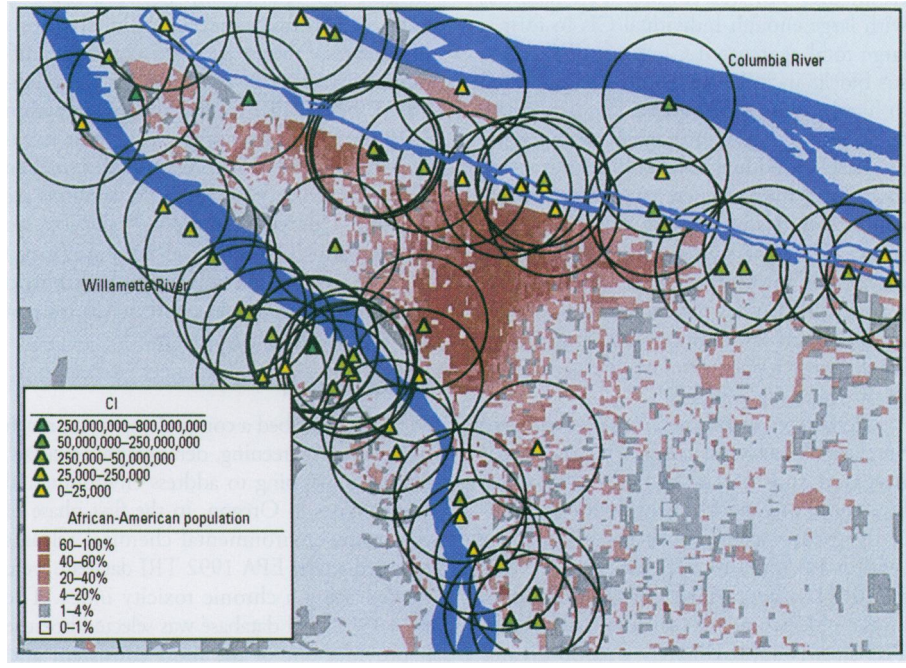

Figure 2. Bivariate mapping of total on-site chronic toxicity index (CI) and percent black population. This is a map of north Portland, Oregon, showing census-block boundaries. Circle radii around each Toxic Chemical Release Inventory (TRI) facility are 1 mile.

The CI for each facility can be aggregated from multiple sites in close proximity to each other. Table 10 lists the top 10 total aggregated on-site CIs from multiple TRI facilities that are within 1.0 mile of one or more census blocks. Each unique block listed in this table is within 1.0 mile of one or more different TRI sites. The same site could be within 1.0 mile of more than one census block. For example, as shown in Table 10, the four TRI facilities that include those with the second and third highest CIs but are ranked 19 and 37 by mass are both located within 1.0 mile of 28 census blocks in urban Portland and involve a total population of 1,653. The largest aggregated CI from multiple sites occurs among facilities with high individual CIs such as the sites listed in Table 9. The range in toxicity for chemicals reported in the Oregon TRI and therefore the range of on-site CIs is so broad that the individual indices calculated for the top 20 facilities mask the aggregated indices from multiple facilities with smaller individual indices. Although there were some census blocks

Table 10. Areas with highest aggregated total chronic index (CI)

No. census blocks	Total population[a]	Total CI[b]	No. TRI sites[c]	Percent minority population[d]
28	1,653	1,795,439,348	4	20
2	8	1,792,668,159	1	0
3	27	1,598,286,051	1	0
101	6,903	1,105,144,828	3	15
20	1,412	1,104,983,950	2	15
26	1,731	$9.1–9.2 \times 10^8$	4	16
93	3,285	$9.0–9.1 \times 10^8$	3	12
167	8,267	886,239,094	1	24
1	2	623,492,097	6	0
51	2,455	494,634,769	1	4
133	6,889	$4.0–4.9 \times 10^8$	6	6

TRI, Toxic Chemical Release Inventory.

[a]Total population living in selected census blocks (1990 U.S. Census block level data) within 1.0 mile of TRI site(s) with same total aggregated CI.

[b]Sum of total on-site chronic indices for all TRI facilities within 1.0 mile of census blocks.

[c]Number of TRI sites within 1.0 mile of census block.

[d]Percent minority population including black; Asian or Pacific Islander; American Indian, Eskimo, or Aleut; and other nonwhite races.

with as many as nine TRI facilities located within 1.0 mile of a particular block centroid, they did not contain TRI facilities with large enough individual CIs to form a large total aggregated CI. Most of the census blocks included in Table 10 are located in highly dense urban areas. The percentage of racial and ethnic minorities within some of these individual census blocks is more than three times the percentage found within the counties containing these industrial sites. However, when these blocks are aggregated into larger units, such as areas within 0.7–2 miles around individual sites as described in Table 5, the individual blocks with higher proportions of minorities are partially masked.

Results of estimated income analysis. Statistical analysis using a paired *t*-test revealed that estimated block median household income for counties are substantially greater than those for areas close (within 1.0 mile) to TRI sites ($t_{253} = 5.55$; $p<0.001$). The average estimated median household income for counties that contain TRI sites is approximately $2,666 greater than that for sites within 1.0 mile of a TRI facility (95% confidence interval, 1,720–3,610). These results did not change when inference was restricted to number of households ≥10 or for sites not ranked with a CI. Although the estimated income was greater in the county containing the TRI site compared to those of the near-site areas, the average estimated median household income of the 27 counties in Oregon containing TRI sites was $26,432 compared to only $22,997 for the nine more rural counties with no TRI sites. These results are consistent with national data showing that rural counties have lower median household incomes than urban counties (*15*). Scatterplots of income or differences in income (county minus site) compared to CIs of the TRI facility do not suggest any relationship between the two variates. Nonparametric Wilcoxon tests demonstrate that there is no significant difference ($p = 0.702$; $z = 0.388$) in the median CI for the TRI facility and areas (within 1.0 mile of the site) with positive or negative differences in income and the median CI for the county in which the facilities are located. Correlation analysis showed no relationship between total amount (mass) of TRI chemicals released on-site and median income in areas within 1.0 mile of the site ($r = 0.044$; $p = 0.496$).

Discussion

We have described a comprehensive approach using hazard screening, demographic analysis, and GIS mapping to address environmental equity issues in Oregon. In the first phase of the study, environmental chemical releases reported to the EPA 1992 TRI database were ranked using a chronic toxicity index. The EPA 1992 TRI database was selected because it provides one of the most consistent and comprehensive databases of industry-reported annual chemical releases to the environment. This environmental information resource was designed to encourage pollution prevention and waste reduction by increasing public access to and knowledge of environmental chemical releases (*2*). The TRI database has several limitations for environmental health research (*8,19,30*). First, only industries classified under the Department of Commerce's Standard Industrial Classification codes 2000–3999 (*31*) are required to report releases under EPCRA. An additional list of seven new industrial categories will be added in 1998. Second, a limited list of 370 chemicals and chemical classes was required to be reported during the 1992 TRI reporting year; an additional 286 chemicals were added to the TRI list in 1996 (*32*). This list of 656 chemicals represents only a small percentage of the 60,000 chemicals currently in commercial use (*33*). Third, the EPCRA reporting thresholds further limit the number and type of facilities required to report to the TRI database; these thresholds include companies that manufacture or process quantities greater than 25,000 lbs of chemicals per year, use quantities greater than 10,000 lbs/year, and/or have 10 or more employees. Therefore, companies (i.e., solvent-recovery services, dry cleaners, auto body shops) that may release substantial quantities of chemicals into the local environment are not required to report chemical emissions to the TRI database. This study uses TRI data from 1992 and demographic data collected in the 1990 Census. Between 1990 and 1992, there could have been significant individual annual changes in the TRI in both the list of companies submitting forms and the amounts of chemicals reportedly released. For example, the facility ranked fourth by CI in 1992 did not report to the 1990 TRI database, which would result in changes in aggregated demographic data around sites of interest. A major limitation of the TRI database is reliance on best professional estimates rather than measured releases. The EPA conducts only periodic inspections of facilities required to report under EPCRA. These enforcement efforts are designed to improve and maintain the accuracy and completeness of the database, but they are limited in scope. Other components of the TRI database that must be verified and often corrected are the longitudinal and latitudinal coordinates of each TRI facility. After cross-checking using an address- and zip code-matching program, inaccuracies were identified in 30% of the coordinates reported in the original TRI data set for Oregon.

Hazard screening methods other than the CI have been used to rank environmental chemical releases (*5–8,30*). Earlier studies by O'Bryan and Ross (*5*) used 11 separate scoring parameters to rank environmental chemical releases, 6 of which pertain to chemical toxicity; the remaining 5 parameters were related to environmental fate. Welch and Ross's (*6*) scoring system combines environmental release and distribution potential with information pertaining to each chemical's mobility and persistence in air, water, and soil. In another study, Stockwell et al. (*7*) applied a 10-point scale using seven criteria to evaluate potential adverse human health effects (e.g., carcinogenicity, heritable genetic mutation, reproductive toxicity, etc.) and three indicators of potential adverse ecological effects (environmental toxicity, persistence, and bioaccumulation).

The CI method offers a refinement over existing toxicity-weighting approaches. First, it gives full priority to protecting public health, including potential high-risk groups, by defining the toxicity of a TRI chemical according to its adverse critical health effect. The adverse critical health effect is determined by extensive peer review of both human epidemiology studies and experimental data. A noncarcinogenic reference dose below which the effect is not likely to occur is then derived for each TRI chemical (*20–22*). Also, cancer potency factors are conservatively designed to protect public health and to apply to all population sectors. In contrast, Horvath et al. (*8*) recently proposed using TLVs to estimate relative hazard and to rank chemical releases by major chemical companies across the United States. Although this method is noteworthy, TLVs are intended for occupational rather than environmental settings and generally apply only to healthy worker populations (*9–11*). A second strength of the CI approach is that it allows standard comparison of carcinogenic and noncarcinogenic chemicals according to their relative dosages and results in a more refined comparison of TRI releases in terms of their relative toxicities.

Hazard-screening methodologies such as the CI are often limited by the availability of toxicity data for specific TRI chemicals. In the present study, 67% of all TRI chemicals (85% of the total mass) had oral toxicity factors available and thus could be ranked using the CI approach. The CI relies on oral toxicity factors because of a lack of availability of inhalation reference doses for TRI chemicals. Inhalation reference concentrations (RfCs) would be more appropriate for ranking TRI air releases; however, less than 50 chemicals have RfCs. Recent preliminary evidence suggests that using either inhalation or oral toxicity factors does not significantly change the final rank (D.L. Forman, personal communication). On a media-specific basis, 90% of all stack and 83% of all fugitive air releases could be ranked. This is important because 80% of the total mass of TRI chemicals was released into the air. In contrast, Horvath et al. (*8*) could only rank 59% of TRI chemicals or chemical classes constituting 78% by mass using the Carnegie-Mellon University-Equivalent Toxicity method. Another common problem to all toxicity-weighting models is that TRI reporting is not specific for chemicals with multiple valence states (e.g., Cr^{+6} and Cr^{+3}). To be conservative, the CI assigns metals with different valences the more toxic oral toxicity factor; this may generate a result that overemphasizes the actual hazard.

A limitation of the CI approach is that it only considers the hazard identification step in the risk assessment process (*13*). Recently, Jia and Di Guardo (*30*) described a four-stage model designed to characterize more fully the toxicity, persistence, and environmental fate of TRI chemical releases. Although this model is sophisticated, it relies heavily on physical and chemical properties to estimate environmental partitioning and potential for exposure. As the authors note, consensus is needed on the scientific accuracy of these factors before wide-scale application of this approach to environmental health research (*30*). A second limitation of the CI is that it only considers chronic toxicity and does not address acute toxic effects. Including acute toxicity ranking would help identify facilities that pose the greatest risks following industrial accidents. Recently the the EPA Region III Air, Radiation and Toxics Division has developed a multicomponent chemical-indexing approach that includes acute toxicity as well as environmental fate of TRI chemical releases. In addition, the CI approach has been recently modified so that chemicals that may pose chronic risks but do not have oral toxicity factors may be classified as residual releases and be included in a combined index (*34*). This refinement enables 100% of the mass reported to the TRI to be analyzed. Another limitation to this approach is that the CI considers only adults because toxicity values (RfD and CPF) are based primarily on adult animal experiments and human epidemiological studies of worker populations. The EPA is currently addressing this issue by identifying a group of chemicals that may be more toxic to children. To account specifically for children, one must incorporate appropriate child-specific exposure parameters. For example, the total CI for each TRI chemical release may be larger for children because of their lower body weights.

The current CI approach provides a reasonable basis for identifying and screening potential hazards and is a marked improvement on the past practice of simply adding up total mass of TRI releases for individual facilities or an entire state. Moreover, because a CI value is calculated for each chemical release, individual CIs may be aggregated by chemical, environmental media, facility, or industrial sector. Results of CI ranking may be used to assist in targeting scarce resources within a state for enforcement targeting and pollution prevention activities at the local, regional, or state level. For example, glycol ethers were identified as the top TRI chemical released on-site in 1992 using the CI approach; in contrast, methanol was ranked as the top TRI chemical based on total mass reportedly released. Therefore, Oregon pollution prevention activities may focus more on reducing total glycol ethers emissions than methanol. However, it is important to keep in mind that the results of this ranking are limited by the scope of the TRI chemical list. Pollution prevention priorities would vary if all chemical emissions were considered in the hazard screening process, e.g., those from hazardous waste sites or hazardous air pollutants not currently listed under EPCRA.

Results of this study demonstrate that industrial emissions from manufacturing facilities reported in the 1992 TRI database for Oregon are disproportionately found in communities with higher percentages of minority populations and lower average incomes than the counties overall. Using block-level data from the 1990 U.S. Bureau of the Census for socioeconomic characteristics is a unique aspect of this study. Previous studies (*7,15–17*) generally used for analysis larger geographic units such as block groups, census tracts, municipalities, counties, and states. Relying on demographic data from these larger geographic units can mask local variations and obscure various anomalies such as minority or low income clusters. In rural areas, block-group and tract data can apply to areas much larger than actual areas of potential contamination from an industrial site. GIS allows investigators to define distances from a given point (i.e., industrial point source) or polygon (i.e., waste site, plume, etc.) that are most appropriate for particular studies and not to depend on predefined geographic boundaries and spatial units (i.e., census-tract areas). A limitation of this geographic technology, however, involves assuming homogeneity across census blocks when aggregating socioeconomic data from census-defined areas that have been split by a GIS-created boundary, such as a circular radius drawn around a point emission.

Results of past studies indicate that TRI facilities may be disproportionately located among low income groups with predominantly high minority populations (*14–17*). Zimmerman (*17*) found a disproportionate designation of National Priority List Superfund dumpsites in poorer communities with higher percentages of minorities; however, this trend appeared to be reversing itself. Although the population of Oregon is predominantly white, the methods presented in this paper for hazard ranking of industrial sites and statistical analyses of demographic data proximate to sites are applicable to other states with higher proportions of racial and ethnic minorities. Not only do the statistical tests used here account for comparisons of percentages of large and small groups, but other studies involving broader areas such as the entire United States include aggregating

data from larger geographic areas, which may mask smaller important regional variations. Although most people living within 1.0 mile of a TRI site in Oregon are white—about 90% versus only 4, 1, 3, and 5% for blacks, Native Americans, Asians or Pacific Islanders, and Hispanics, respectively—racial and ethnic minorities are disproportionately located close to the industrial facilities. Almost 60% of blacks, 34% of Asians or Pacific Islanders, and 33% of Hispanics live within 1.0 mile of a TRI facility in Oregon compared to only 24% of the white population. In addition, estimates of median household incomes in counties containing TRI sites are substantially larger than those in areas close to the sites.

Previous studies have reported that minority groups tend to live in counties not only with more TRI facilities but also with higher industrial emissions (pounds per year) than the counties with high proportions of whites (*15*). The current study demonstrates that neither the total pounds released nor the hazard ranking of TRI facilities based on chronic toxicity factors for both cancer and noncancer effects is associated with racial, ethnic, or income census data. Importantly, analysis of near-site demographic data suggests there is no relationship between the CI of the facility and socioeconomic characteristics.

Comparative toxicity ranking together with demographic analysis can identify communities with potentially greater risks of exposure to hazardous chemicals. Future studies may involve dispersion modeling and environmental fate of TRI chemicals to obtain more accurate estimates of exposure. Using the GIS enables researchers to build multiple layers of environmental, health-related, and socioeconomic data that contain geographic variables for locations. This integration of hazard screening, demographic analysis, and computerized mapping should serve as a model for the assessment of environmental equity issues at the local, state, or federal level. It has been recommended that suspected hazards be evaluated more rigorously by combining this method with available methods for exposure and risk assessment (*35*). This approach may assist in identifying communities that may warrant environmental monitoring to assess whether exposure or health hazards actually exist.

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